EXPERT SYSTEMS
A PRIMER FOR THE CONSTRUCTION MANAGER

BY

HENRY V. DOBSON, JR.

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
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ABSTRACT

Construction managers are only beginning to realize the true potential of the microcomputer. Computer systems for such applications as estimating, scheduling and cost control have been popular for many years. However, these applications are primarily limited to "number crunching" and data manipulation. Computer systems that can make decisions and choose between alternative problem solutions are the next step towards computerization of construction management. The computer field of artificial intelligence has provided the "expert system" which simplifies the creation of decision making systems.

To better understand the application of expert systems to real construction management problems, an understanding of the expert system itself is required. Following the discussion of expert systems in general, a summary of existing applications in construction management is provided. These applications range from more common uses such as estimating and scheduling to newer ideas such as planning, equipment selection and optimization, and site layout. These systems serve to assist the construction manager by analyzing possible alternatives and making recommendations based on the knowledge that the system possesses.

As part of this paper, an expert system was created for selection of earthmoving equipment. This expert system is presented to show the process used to develop a construction

management application. The system was developed on an expert system shell called Personal Consultant Easy which is marketed by Texas Instruments Incorporated. Following the presentation of this system, a sample consultation with the expert system is provided.

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CHAPTER ONE
INTRODUCTION TO EXPERT SYSTEMS

1.1 Problem Solutions and the Expert

In today's business environment, the expert problem solver is a highly desirable asset. Problems requiring the attention of an expert are in every facet of business and technology. Development of a human expert is often time consuming and expensive and that expertise is subject to the frailties of the human mind and body. The human expert may leave the company and take all corporate knowledge elsewhere, leaving the business to struggle until a replacement expert can be found. The human expert is also expensive to maintain, especially if the expertise is tapped only on an occasional basis.

What is needed is a way to clone the expertise of the expert. That clone could be used when the expert is away and can serve as an invaluable training tool for up and coming junior experts. The clone could also be quite useful for businesses with limited need for a particular expertise. The concept of cloned intelligence may sound futuristic and may evoke thoughts of robots with human form. However, the concept is not futuristic but is available now in the form of computerized expert systems.

1.2 Definition of Expert Systems

As mentioned above, an expert system is a computerized clone of human intelligence. The clone is actually a structured collection of information used to analyze a certain

type of problem. The expert system systematically reviews its knowledge to find the specific conditions that will satisfy the problem statement. This ability to review a collection of information and draw conclusions about stated problems is what sets the expert system apart from traditional data intensive computer programs.

According to Han (1: p.300), expert systems are the highest form of information management system. Expert systems may include the powers of a database management system to allow for efficient storage, processing, and retrieval of data. They may also include the ability of a decision support system which allows for data analysis and trend forecasting. By use of the collection of information, the expert system will use judgement, experience, and rules of thumb to solve problems.

The scope of problems that a system may successfully solve is always limited. Systems tend to be either broad (limited knowledge about multiple fields of study) or deep (extensive knowledge about a narrow field of study) in their scope. To be both deep and broad in knowledge requires vast amounts of information, making the system difficult to use. The most practical expert systems generally have a narrow scope and are able to solve many variations of the same problem (2: p.79).

Expert systems can be divided into three general overlapping categories. The most basic of these is the job

aid system which is intended to assist and train new employees. The second level of expert system is the apprentice system. The apprentice system assists the human expert by taking on more time consuming, data intensive functions. The highest category, the true expert system, solves problems that would otherwise require the full attention of an expert. In essence, the true expert system is a clone of the human expert and can be operated even by a non-expert. The true expert system fulfills the role of all lower categories and is therefore the focus of this paper (3: p.1-9).

1.3 History of Expert Systems

Although research in the area of expert systems has been ongoing since the 1960's, only in the last decade have commercial systems been readily available (4: p.300). The earlier systems were created in the name of research but the more modern systems have actual applications in the business world. In fact, the emergence of commercially viable expert systems in the present world market was a direct result of this earlier research. As with most new technologies, the average cost and development time for expert systems has decreased significantly since their advent. The emergence of the expert system shell played the key role in reducing system design time (4: p.301).

Early expert systems were created directly from computer programming languages. As each new system was developed,

system control strategies and search techniques were repetitively recreated. However, since all expert systems share similar programming environments, the generic expert system shell was developed. One early shell came about by removing the medical knowledge from a medical diagnostic system called MYCIN. The empty MYCIN program was dubbed EMYCIN (empty MYCIN) and was used to develop expert systems in other problem areas. The expert system shell is firmly established with nearly 100 commercial shells available in today's market (5: p.2471).

Early research in problem solving indicated the importance of domain specific knowledge. Domain specific knowledge is the information that the human expert uses to solve problems. It includes information about the problem as well as an approach to problem solution. Researchers found that expert systems require a detailed field of knowledge about the problem domain (the area of study to which the problem belongs) as well as an inherent problem solving ability. This requirement for domain knowledge causes expert systems to be limited to well studied, clearly defined problems. Problems that depend on a more loosely defined notion of common sense are much more difficult to solve by expert systems.

In spite of great expectations for application of expert systems to real world problems, the systems still lack many

human problem solving abilities. According to Luger (4: p.17), these deficiencies include:

A) Difficulty in capturing deep knowledge of the problem domain. Current systems can review programmed knowledge and imply solutions in the absence of complete knowledge, but the programs have no real understanding of the problem itself.

B) Lack of flexibility. The expert system will try to solve the problem by reviewing its knowledge. If no immediate solution is found, the system has no real ability to examine the principles behind the problem to create an alternate problem solving strategy.

C) Inability to provide deep explanations. Because of an inherent lack of deep knowledge, detailed explanations of the problem's solution are limited. Systems generally rely on a restatement of the rules used to solve the problem.

D) Difficulties in verification of information. It is nearly impossible to determine the correctness of a system's decision. As systems are applied to critical problems like air traffic control or plant operations, evaluation of system performance is critical.

E) Little learning from experience. Once a system is created, the program will not develop further knowledge without additional programming.

As early as 1950, researchers were considering the concepts of machine intelligence. One of the pioneers in the field, Alan Turing, proposed that machine intelligence be judged by a simple empirical test. The essence of the Turing test was that a truly intelligent computer could not be distinguished from its human counterpart. Communication with the computer was limited to a textural device such as a computer terminal. The Turing test is still applicable today and variations of it are used to test and evaluate modern expert systems (4: p.10).

1.4 Myths Surrounding Expert Systems

One of the key factors limiting the wide spread use of expert systems is the amount of misinformation surrounding their purpose and powers. According to Liebowitz (6: p.26), the following myths are quite common to the casual observer:

A) Myth: Expert systems do not make mistakes. Since the system is only as good as its collection of information, the system is no more perfect than its programmer. It is extremely difficult to compile a set of rules that covers all possible problem situations.

B) Myth: Expert systems can learn from their mistakes. Current computer technology does allow the computer to learn from its errors but typical expert systems do not include that capability. System mistakes are generally corrected by further programming.

C) Myth: Expert systems will replace employees. Most

systems used today serve as supplements to the decision maker. Some systems may, however, be developed to replace experts in cases where the expertise is scarce, expensive, or infrequently used.

D) Myth: Expert systems are hard to use. Since better systems are menu driven and contain help features, little computer knowledge is required.

E) Myth: Expert systems are only useful in high tech industries. Expert systems are quite useful for preserving the corporate knowledge of experts who plan to retire or leave the company. They are also useful for verifying opinions and aiding decision making under time and pressure constraints.

Only by overcoming the fears of future system users will the expert system be welcomed into the workplace.

CHAPTER TWO
EXPERT SYSTEMS IN GENERAL

2.1 The Reasons for and Limits of Expert Systems

The reasons for using expert systems are many and varied. Since an expert system mimics the expertise and problem solving ability of the human expert, it serves to assist the expert or confirm previous problem solutions. Expert systems function when the expert is not available and aid in retention of corporate knowledge from departing experts. Expert systems may actually replace the human expert in cases when human expertise is either unavailable or too expensive to retain. Expert systems are not, however, viewed as a replacement for human expertise, but are intended to aid the expert by solving more routine problems. This, in turn, frees the human expert to attack the more complicated, unstructured problems.

To better understand the purpose of the expert system, it may be useful to contrast them with traditional computer programs. Expert systems solve problems based on knowledge and rules while conventional programs rely on numerical calculations or character data for decision making. Conventional programs produce large amounts of information from small amounts of data while expert systems produce concise solutions from large collections of information. Expert systems are capable of explaining the problem's solution while traditional programs simply provide an answer. Finally, expert systems are best suited to solve qualitative

problems while conventional programs solve problems quantitatively (7: p.45).

While expert systems may be a great leap in application of computer intelligence to everyday business, their limitations must be understood. First and foremost, users must remember that expert systems are not perfect and are only as good as their programming. Second, expert systems generally lack common sense, true intuition, and the ability to learn. While these qualities may be mimicked with some degree of success, computer systems with true intuitive behavior are not currently available. Finally, system performance deteriorates rapidly as the system approaches the limits of its expertise. Because of these inherent limitations, expert systems are well suited for problems involving deduction but are not as appropriate for problems requiring induction or analogy (7: p.9).

2.2 Expert System Architecture

To properly clone the expertise of the human expert, the expert system must accomplish two tasks. First, the system must possess the knowledge associated with the experts domain. Then, the system must have the ability to take a problem statement and reach a conclusion using the knowledge it possesses. Better systems are also capable of inferring a solution even in the absence of conclusive information. Only by cloning these two parts of the human expert may a true expert system be created.

2.2.1 The Basics

The primary components of an expert system are the user interface, the inference engine, and the knowledge base (shown in Figure 1). The user interface is simply a natural language front end that allows for simplified communication between the user and the system. The inference engine contains the system control strategies that provide the generic problem solving ability. The knowledge base provides the information and knowledge needed to solve problems in the system's domain. Modern expert system shells include the user interface and the inference engine as well as providing a structured environment for knowledge storage (7: p.46).

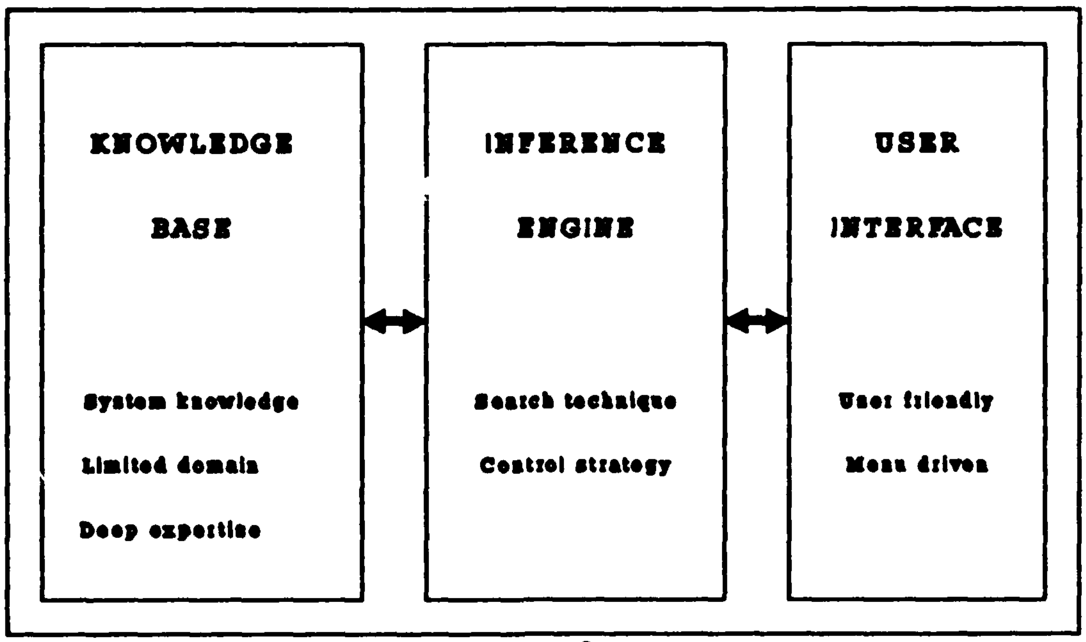

Figure 1. Primary components of an expert system

Since the user interface is the system's communication mechanism with the user, it must be attractive and friendly.

The interface should be menu or graphics driven since target users may have little or no computer programming skills. The interface serves to interpret the computer based knowledge into natural language that the user can easily understand. Better expert systems also include an explanation facility here to describe the reasoning associated with its problem solutions. This explanation facility serves the dual role of allowing the expert to check system performance and educating users with lesser expertise. The user interface is the key element in selling a prototype system to higher management and for attracting the more skeptical user.

The inference engine is generally considered the brain of any expert system. It provides the structure and organization necessary to solve problems using the vast amount of information in the knowledge base. It contains the information search techniques and system control strategies necessary for system operation. To properly function in a true expert system shell, the inference engine must be generic in that it can handle information from different problem domains. While it is the least seen or understood of the three system components, the inference engine plays the leading role in a successful expert system.

The knowledge base contains the information that the inference engine uses to solve problems. The information is an organized collection of rules that may be structured in several ways (to be discussed later). The knowledge base is

created through the user interface and must be continually updated as new facts are discovered or flaws are found in the system. The size and organization of the knowledge base limit the scope of the system's problem domain. Since expert system shells provide all other components necessary for system development, the task facing expert system designers is creation of an organized knowledge base.

2.2.2 Knowledge Representation

Information in the knowledge base may be represented in several different ways. The most popular forms of knowledge representation are rule based and frame based. Rule based systems are best suited to problems requiring seemingly independent assertions and conclusions. Frame based systems, however, are appropriate for problems of a hierarchical nature. Because different knowledge representation techniques require appropriate inferencing schemes, the inference engine must be matched to the knowledge base organization.

2.2.2.1 Rule Based Systems

A rule based knowledge base is best viewed as a collection of if-then statements which contain all known information about a particular problem domain. An example of an if-then rule is as follows:

IF the earthmoving project involves trenching
AND the trench is less than 25 feet deep
THEN a trencher may be used.

To maintain rule independence and to allow for system

expansion, no particular sequence is given to the rule base. This type of knowledge base is closely tied to traditional programming techniques. The expert system, however, can make assertions based on conclusions reached by evaluating each rule. These assertions are then used when evaluating the remaining rules, which will hopefully lead to other assertions and ultimately to a solution (7: p.47).

The most basic rule based expert system will evaluate rule after rule until a rule yields some piece of information. That information is then stored as an assertion and the system continues or starts over and evaluates each rule considering the assertion previously gained. The system will continue to cycle through the rules until every rule is analyzed and no new assertions are made or a solution is found. More sophisticated systems will flag rules that cannot be satisfied by currently known assertions and flag rules that have already yielded an assertion.

The most sophisticated rule based systems will query the user if it reaches a dead end. If reevaluating all rules yields no further assertions and no solution, these systems will determine which rules are close to yielding an assertion or conclusion. These rules are then used to formulate questions to ask the user. Systems that ask

rational related questions about the problem appear to be truly intelligent from the perspective of the user.

Rule based systems may encounter conflicting rules in a truly independent rule collection. One way that systems avoid this is by only drawing an assertion from one rule on each pass through the rule list. While all rules are evaluated, a priority system or a separate set of rules will determine which rule will yield an assertion. These priority systems or rules about rules are called meta-knowledge, which is knowledge about the nature of the rules themselves.

Rule based expert systems have one major advantage over other types of knowledge representation schemes. Because the rules are independent of each other, rules may be added, modified, or deleted without affecting other rules in the system. This simplifies construction and maintenance of the rule base. Along with this advantage of rule based systems comes several limitations. They are inherently slower because they repeatedly search the rule base seeking new assertions. Also, search efficiency degrades rapidly as the size of the rule base increases. This may be mitigated by organizing the rules into some logical order but care must be taken to maintain rule independence (7: p.49).

2.2.2.2 Frame Based Systems

Unlike rules, frames provide a method of organizing knowledge into a hierarchical structure while retaining some degree of knowledge independence. A frame is a data structure that contains a set of named attributes called slots, which describe a concept, object, or event in much the same manner as database fields in a record (7: p.51). Frame slots can hold a variety of information or instructions relating to the subject of the frame.

Frames can be organized in a hierarchical tree fashion so that lower frames inherit information from higher frames. Alternately, frames may be arranged in a lattice structure and individual frames may inherit information from a variety of parent frames. Inheritance is a powerful knowledge representation technique eliminates the requirement to repeatedly enter information that can be drawn from other frames in the system. As shown in Figure 2, the example child frame (trenching operation) inherits information about soil conditions from the parent frame (earthmoving project).

Frame based systems use evaluation techniques that are similar those of rule based systems. A primary advantage of frame based systems is the speed at which the knowledge base can be searched. Since the organization of the frames provides a sense of direction during the search process, only frames related to the

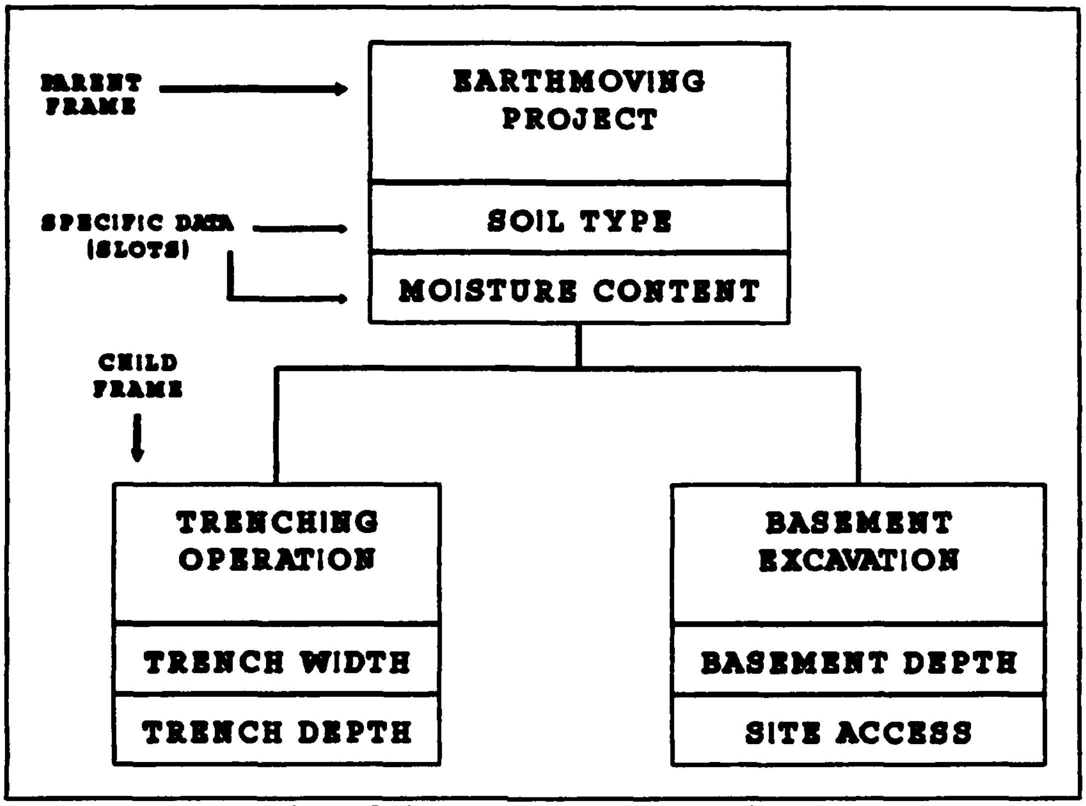

Figure 2. Example of frame based knowledge representation

problem at hand are evaluated. Also, knowledge inheritance allows new objects and concepts to be quickly recognized and integrated into the existing knowledge base.

2.2.3 Knowledge Acquisition

While it is not the most sophisticated or technical part of an expert system, incorporating knowledge into the system is often the most time consuming portion of system development (8: p.20). Knowledge is available from a number of sources depending on the nature of the problem. Knowledge may be in the form of classical textbook theory or step by step cookbook procedures. More complex problems may require information

that only a true human expert can provide. Such information may include knowledge about how to approach the problem as well as technical information about the problem. As technology develops, systems may actually be able to acquire knowledge by experimentation. For example, information gained by solving problems may be retained for solution of future problems.

2.2.4 System Control Strategies

While the knowledge base is best categorized by the way that the knowledge is represented, the inference engine is best defined by the control strategy used. Three primary control schemes are employed to search the knowledge base for assertions. These three schemes are known as forward chaining, backward chaining, and mixed chaining (7: p.54). With several different control schemes and tricks available, it is very important that the control strategy match the expected problem domain as well as the knowledge representation system.

Forward chaining is a data driven process whereby all rules in the knowledge base are checked and rechecked in a sequential manner until either a solution is found or the system reaches an impasse. Forward chaining requires no knowledge or insight on the part of the user and requires no prediction on the outcome of the problem solution. While it is the slowest form of system control, forward chaining is the most tolerant of unknowledgeable users (7: p.54).

Backward chaining is a goal driven process that starts with an answer and works backward through the rules to determine which logic, if any, confirms the proposed solution. Backward chaining does require a proposed solution which may come from the user or may be generated by the system based on previously encountered similar problems. This control scheme allows the system to only evaluate rules that yield the proposed solution, thereby reducing the search time. The savings realized can be quickly lost if the system must try several different proposed solutions before proving a solution correct. Backward chaining is an appropriate control strategy when the user can predict the problem's solution with reasonable accuracy. Another prime application is when the result is known and the means to reach that result are required (7: p.54).

The third control strategy is actually a combination of forward and backward chaining. This hybrid approach provides quicker search times inherent in the backward chaining systems while allowing the less experienced user to operate the system. The system may use forward chaining to reduce the number of possible solutions to a manageable amount and then evaluate each of these by backward chaining techniques. This approach can shorten search time while requiring no proposed solution from the user (8: p.19).

According to Adeli (8: p.12), the control strategy may involve several other tricks that make the system more

efficient. The problem reduction technique allows the system to break the problem into subproblems that may be solved quickly and easily. The plan-generate-test approach directs the system to generate all possible solutions to the problem and then evaluates these alternatives. Solutions that are inconsistent with the user's information are quickly eliminated, thereby limiting the search to reasonable solutions. Finally, an agenda control strategy assigns a priority rating based on the nature of the problem. Agenda control does require an understanding of the nature of the problem to establish the priority system.

2.2.5 Interfacing and the Integrated System

Since most businesses have parts of their operation already automated, any new computer system added to the business must integrate well with existing systems. Expert systems are no exception to this requirement and must be compatible with other software and systems on the market. Many commercially available expert system shells claim an ability to interface with database and spreadsheet programs. This capability is important, but they should also automatically interact with these and other management software to form truly integrated computer systems. Entire knowledge bases could be generated from existing databases of corporate information, thereby drastically reducing the development time for an expert system. By developing expert systems and shells that are compatible with existing software,

they will become more attractive to skeptical owners and managers.

2.3 Programming Environments and Shells

The tools available for building expert systems can be divided into three major categories. These categories are defined as general purpose programming languages, general purpose representational languages, and expert system shells. While an expert system may be developed using any of the three programming environments, the efficiency of the system and the necessary development time will vary significantly (9: p.15).

Expert systems may be developed at the most basic level with general purpose programming languages. Languages such as LISP, PROLOG, C, FORTRAN, and Pascal are possible choices. Since the expert system developer is starting from scratch, all aspects of the system must be programmed. This means designing and programming the user interface and system control strategy as well as the knowledge base. System designers are able to produce the exact system they want by using basic level programming. The designer will, however, spend much more development time to achieve this custom programmed system (9: p.16).

General purpose representational languages were developed specifically for building expert systems. Their primary advantage over the more basic languages is built in tools for inference engine development. Languages such as OPS5, UNITS, and SRL provide advanced knowledge representation techniques

along with forward and backward chaining capabilities. These languages do simplify system development but advanced programming expertise is required (9: p.17).

Expert system shells provide the less experienced computer user with a means of developing an expert system. The shell supplies the user interface, inference engine, and a structure for the knowledge base. The user is only required to develop the knowledge base within the shell framework. While knowledge base development is no simple task, it is easier than developing the entire system from programming code. Expert system shells also provide a simple way to create prototype systems for analysis. After the prototype is proven and accepted, the full scale version may be built on the shell or with one of the two types of programming languages (9: p.17).

2.4 Expert System Development

While not simple or inexpensive by any means, development of an expert system is within the capabilities of most businesses. The commercial availability of shells has put the expert system in the realm of routine business applications. Figure 3 shows the basic steps to be followed for developing an expert system. According to Maher (9: p.36), these include:

2.4.1 Task Selection

Selection of an appropriate task about which to build an expert system is the first step in system development. The

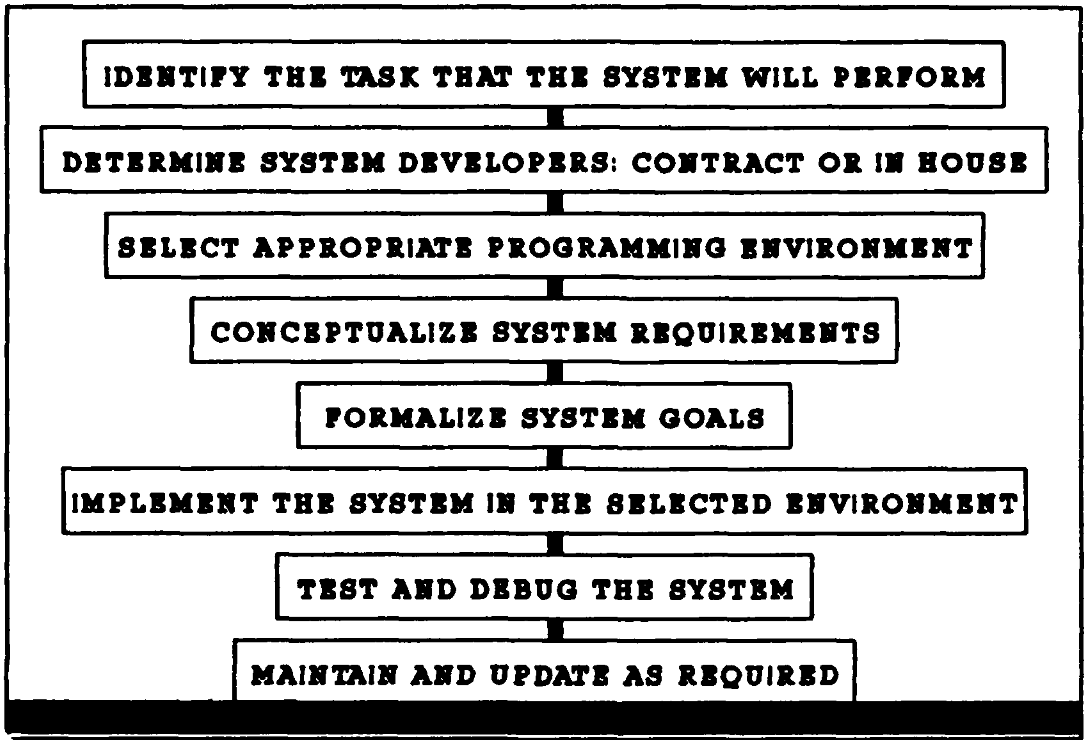

Figure 3. Basic steps for expert system development

task must be suited to the concept of expert systems and the following questions will help make that selection (9: p.35).

A) Is the task clearly defined and rich in reasoning?

B) Is the task one that is performed by an expert reasonably often in a reasonable amount of time?

C) Is the task fairly narrow and domain intensive?

D) Is a substantial library of case studies available about the specific task? These cases are useful for testing the completed system as well as knowledge base development.

E) Does the task have a clear value to the business? Substantial development time and cost must be recaptured for the system to be economically justifiable.

These questions can help narrow the list of potential applications and aid in selection of the ideal task.

2.4.2 The Critical Decisions

Before proceeding, the developer must make several important decisions that will ultimately determine the success or failure of the initiative. Managers must decide whether to develop the system in house or to contract with consultants experienced in the field. Managers may combine these two options by creating a prototype in house and contracting for full scale development.

Developers must then decide which knowledge representation technique and inferencing control strategy are appropriate for the problem at hand. They must also decide whether the system will be developed with a programming language or a shell. A programming language allows for custom tailoring of the system at the expense of development time and cost. On the other hand, an expert system shell will provide simplified development but the developer will be limited to techniques and strategies designed into the selected shell. Following these three critical decisions, developers may proceed with actual creation of the system.

2.4.3 System Development and Implementation

Having the task selected and the development scheme determined, the next step involves conceptualization of the task. In this step, the key attributes of the system are determined and the problem domain is formalized. This process

involves brainstorming by system users and domain experts to define all possible system features. Selection of those features most appropriate to the problem is now made.

Next, system developers will formalize the work performed during the conceptualization stage. This formalization will include a written model of the system with all features defined. Any adjustments to the knowledge representation or inferencing schemes should be made now, before the implementation stage.

Next, the system will actually be implemented on the computer. If a programming environment is selected for system creation, developers will program the user interface and inference engine based on the strategies previously determined. Following this programming (or after selection of an appropriate shell), the knowledge base will be developed.

Development of the knowledge base involves three types of people: the developer, the domain expert, and the knowledge engineer. The developer provides overall guidance with the intent of the user in mind. The domain expert (or experts, in many cases) will provide the knowledge that the system needs to function. And the knowledge engineer, who actually leads the knowledge acquisition process, directs information collection and organization. Before actually collecting the information, the knowledge engineer will gain an understanding of the problem and the approaches used to solve it. Without the expertise of the knowledge engineer, knowledge acquisition

could quickly bog down from listing every fact, relevant or otherwise, that the domain expert can produce.

After knowledge acquisition is complete and the expert system is functional, the testing stage may begin. Since a computer program is rarely perfect after initial creation, the system must be debugged and tested before it is delivered to its users. Testing an expert system involves debugging the knowledge base as well as system operation. Normally, the system is first debugged by repeated operation. This will isolate and correct problems in the program code and procedures. Then the knowledge base and inferencing mechanisms are tested by allowing the system to solve actual problems in its domain. A library of case problems is quite useful for this stage of system development.

Once the system has been adequately tested, it may be delivered to its users. Additional problems are likely to occur requiring additional debugging and adjusting. Also, the system will require continual maintenance to keep the knowledge base current and to correct problems with existing knowledge.

2.5 Legal and Social Implications of Expert Systems

The availability and use of expert systems in making business and social decisions brings about several legal and social considerations. Potential liability for the expert system and its decisions is certainly of concern to developers and users. Social fears and resistance are also important

factors to consider when examining the possible applications for expert systems.

There are several liability issues facing developers and users of expert systems. Potential liability for expert systems can best be described by the following three categories (10: p.122):

A) Liability for incorrect answers provided by an expert system.

B) Liability on the part of the user for unjustifiable reliance on the expert system's solution.

C) Liability for failure to consult available expert systems.

Because of the newness of expert systems, legal liability is not clearly defined. For this reason, it is likely that the judicial system will become involved in these areas.

If an expert system provides an incorrect answer, it must be defective in some way. That defect supports liability issues but the cause of the defect is often difficult to determine. Because of the variety of players who participate in system development, assignment of liability is often impossible. The defect could be the responsibility of the system programmer, the knowledge engineer, the domain expert, or even the user. Since expert systems are of an intellectual nature, strict product liability is seldom applied. Because of this intellectual nature, developers of expert systems must insure that a reasonable standard of care is taken.

Because expert systems are sometimes used to provide expertise in the absence of a human expert, users may be inexperienced in the systems area of expertise. When system users take action based on incorrect information provided by an expert system, liability for any associated damages may exist. If the user is truly inexperienced, the system itself may be liable as discussed above. In the case where the user is knowledgeable in the problem area, the user may retain liability for damages. Even when the knowledgeable user is advised incorrectly, it may be determined that the user failed to provide a reasonable standard of care by not adequately checking the system's analysis.

Finally, professionals may be held liable for failing to use expert systems. Legal precedence holds that liability exists for failure to use available technology. The three elements that must be present to determine negligence are availability of the technology, reliability of that technology for the problem, and a reasonable relationship between technology cost and potential harm caused by its absence (10: p.126). Because of the cost and lack of availability of expert systems, it is doubtful that a professional would be held liable for not having one. On the other hand, it is conceivable that in the future, a professional who fails to use an available system could be held liable for that decision.

The use of expert systems also produces significant social implications. Experts and technicians alike fear that these systems are designed to replace them, or even worse, become their boss. These fears cause human experts to resist sharing the knowledge and expertise necessary to create functioning expert systems. Expert systems also find a general resistance since many potential users have a preconceived distrust for computers and their technology. These fears and resistances must be eliminated before expert systems will be accepted into the business world.

CHAPTER THREE
EXPERT SYSTEMS IN CONSTRUCTION MANAGEMENT

3.1 Introduction to Construction Management

Construction management is a broad area of civil engineering practice involved in the activities necessary to manage construction and related projects. These activities include planning, scheduling, estimating, equipment management, locating temporary facilities, and contract administration. However, these activities are generally not carried out by the firm that designed the project. Because of this separation of design and construction, and because construction is an experience-based industry, construction management is an ideal application for expert systems.

Construction management is far less formalized and structured than engineering design; therefore, problems may have a multitude of solutions. The best solution is usually tied to project cost or completion time or may be related to quality or environmental considerations. Decisions are often urgently needed with no time for in depth analysis or consultation. Also, construction management problems are generally qualitative in nature and require the attention of experienced managers. These types of problems, in theory, lend themselves to expert system technology.

While the potential for expert system development in construction management is apparent, the majority of work in this area has been academic in nature (8: p.123). This is, to some extent, because of a general resistance to change

(especially computerization) by construction managers. The myth that technology is undeveloped and that problems are too difficult for computers to solve has been spread through the construction industry. Another problem challenging expert system developers involves capturing the broad knowledge possessed by construction managers. Construction problems are so varied in nature that it is impractical to develop a single system to perform many construction management tasks.

Since expert systems are best suited to narrow but deep problem domains, system developers must follow that strength and create systems to solve specific problems. In that manner, the systems will be seen as an aid to the construction manager, not a replacement. On the other hand, to function most efficiently, these systems must be integrated together. Systems must be compatible and share common information to eliminate multiple data entry. Based on this concept, the ideal approach is to have a controlling expert system that will interface all existing computer systems with each other and with the expert systems being developed.

3.2 Existing Expert Systems in Construction Management

As mentioned above, construction management is a suitable field for development of expert systems as management aids. Most of the tasks in construction management require the attention of personnel with many years of field experience. The following sections provide an overview of ideal applications for expert system technology with descriptions of

existing systems. It is not intended to be a catalog of all available systems, but only serves as an example of construction management applications. Table 1 lists these systems in the order in which they appear in the text.

Table 1. Summary of expert systems in construction management

TITLE	APPLICATION	SOFTWARE	STATUS	DEVELOPER
MIRCI	planning	Leonardo 3	prototype	Univ. of Salford
GHOST	planning	IMST	completed	D Navinchandra
CSA	scheduling	Personal Consultant+	under development	U S Army
MASON	scheduling	OPS-5	prototype	Carnegie-Mellon Univ.
PREDICTE	project duration	Candel	complete	Civil + Civic Inc., Sydney
TIME	scheduling estimating	Prolog 2	prototype	Univ. of Reading GB
ESEMPS	equipment selection	Savoir	complete	Univ. of Technology GB
EXSIM	equipment optimization	Exsys	complete	Northeastern Univ. Boston
CRANE	equipment siting	VPExpert	under development	Worcester Polytecnic
SIGHT PLAN	temp facility layout	Accord	under development	Stanford Univ.
SAFEQUAL	site safety	The Deciding Factor	complete	Bldg Systems Knowledge
HOWSAFE	site safety	The Deciding Factor	prototype	Bldg Systems Knowledge
IRIS	Risk Analysis	M1	under development	Univ. of Texas, Austin
PROPICK	contract type selection	The Deciding Factor	complete development	CM Consultants
BIDEX	bidding strategy	Exsys	under development	Irtishad Ahmad
Qual-1	contractor qualification	FORTRAN 77	complete	Jeffrey Russell
CPO-ES	project organization	The Deciding Factor	prototype	Motor Columbus
CGS	Claims Analysis	Personal Consultant+	complete	U S Army

3.2.1 Project Planning

Planning a construction project is one of the most experience intensive tasks facing construction managers. Using construction drawings, planners must break the project into manageable activities for use in project scheduling, estimating, and control. While the activities or items created will differ for estimating and scheduling, the goal of dividing the project into manageable parts is the same. The expertise involved in the planning process appears to be suitable for incorporation into an expert system.

The planner uses knowledge of the construction process to create interdependent activities for construction scheduling. This expertise allows the planner to create activities from construction plans and to determine activity dependencies considering work progression and phasing. Division of the project into activities is often based on different aspects of construction such as floor slab, walls, roof, etc. Alternately, activities can be based on different construction materials (steel, concrete, etc), subcontracted portions of the project (electrical, plumbing, etc), or some other planning scheme. This diversity in planning strategies has severely limited development of successful planning systems.

The most difficult portion of developing a planning expert system is cloning the ability to create scheduling activities and estimating items. Since these activities and items must come from the construction plans, developers must

look to computer aided drafting (CAD) drawings as a source of information. Since many other computer developments in construction and manufacturing also depend on CAD knowledge transfer, CAD systems are currently being modified to allow for this sharing of information. A conceptual system called MIRCI claims an ability to create a list of activities. MIRCI does, however, require exhaustive questioning of a knowledgeable user, thereby defeating the purpose of the expert system (11: p.373). Until such information sharing is available, development of complete planning expert systems is unlikely (12: p.87).

While expert systems are not yet capable of creating scheduling activities, they are able to determine dependency relationships between activities. The dependency decisions made by expert planners can be cloned by an expert system and used in creation of project scheduling plans. An expert system called GHOST is capable of creating these dependencies based on a list of activities (with durations) provided by the user (13: p.239). The system uses a knowledge of basic physics, construction practices, and network scheduling to determine logical dependencies between activities. Based on the established dependencies, the system provides a construction schedule using the critical path method (CPM). GHOST is part of CONPLAN, which is a larger integrated construction planning system that is being developed.

Great potential exists for creation of successful expert systems in project planning. Further development of knowledge sharing between CAD systems and expert systems will likely lead to automated project planning (11: p.450 and 485). This information sharing will allow automatic creation of estimating items as well as scheduling activities. With this ability established, expert systems such as GHOST can be expanded to create total planning programs. Activities and their associated dependencies can then be passed to existing estimating and scheduling programs to create truly integrated project management systems.

3.2.2 Project Scheduling

While project planning is waiting for technology advances, project scheduling has been automated for many years. In using these systems, the scheduler is generally required to enter a list of activities with durations and dependencies. In this manner, current scheduling software is confined to number crunching and CPM calculations. To expand the abilities of current scheduling programs, an expert system can act as a sophisticated front end and provide additional features.

Since the schedule will have been previously established, the front end will focus on analysis, monitoring, and control. Expert systems could provide such features as schedule verification, advanced resource leveling, procurement management, and schedule updates. Again, it appears that work

in this area is largely conceptual in nature with few actual systems being developed.

Construction Schedule Analysis (CSA) is one system that is under development by the U.S. Army Corps of Engineers (9: p.98). This system operates under an expert system shell called Personal Consultant Plus which is marketed by Texas Instruments. It is integrated with dBASE III+ database management software and Primavera project management software, and provides a sophisticated schedule analyzer. In addition to the scheduling ability of Primavera, the system is intended to provide an evaluation of activity durations, scheduling logic, and project pricing.

Another system, called MASON, which provides limited scheduling information is being developed at Carnegie-Mellon University (9: p.93). MASON is intended to estimate masonry activity durations and recommend crew configurations and construction techniques. The program considers working conditions and problems to adjust the calculated productivity and activity duration. This type of system could be developed for many other areas of field work and resulting information can be provided directly to the scheduling system.

In its most general sense, scheduling is aimed at providing an estimate of total project duration. PREDICTE is one expert system that provides project duration estimates during the preliminary phases of project development (11: p. 590). The system is limited to construction of multi-story

buildings. Based on a questionnaire answered by the user, PREDICTE anticipates the likely design, determines appropriate construction techniques, and estimates project duration. The system includes a detailed explanation facility to describe the logic used to reach its solution.

One of the drawbacks of this system is the length of the questionnaire. With some 223 questions available to the system, the user spends about 30 minutes entering information about each project into the computer. PREDICTE does provide a consistency check to insure that all user responses are consistent with previous responses. Based of the results of the questionnaire, the system generates a list of activities with estimated durations and simple dependencies. The list of activities is then presented for user analysis and then is used to generate total project duration.

Based upon early testing of PREDICTE using previously completed projects, the system provided estimates within eight percent of actual project duration (11: p.601). Users are quite satisfied with system performance, but since the system is only two years old, no examples can be given for completed projects which used PREDICTE at the conceptual stage.

3.2.3 Cost Estimating

As with scheduling, detailed cost estimating has been computerized for quite some time. And like scheduling software, estimating programs are generally limited to numerical calculations. As discussed above, automated expert

computer estimators require quantity take-off information that is only available from CAD drawings (11: p.453). While automated quantity take-off is possible using a built in AUTOLISP programming language in AutoCAD, the technology is not adequately developed to support automated estimating (11: p.491). Until such time that information sharing becomes practical, expert systems will be limited to estimate analysis and update.

While detailed estimating expert systems are not currently available, several scoping estimate systems have been developed. Like PREDICTE, these scoping estimate systems attempt to generate a rough idea of project cost during the conceptual stages of project development. The estimates are based on general project information, not on detailed construction drawings and data.

While project design is usually separated from project construction, designers must consider the cost and time implications of their decisions. To aid the designer in making cost and time conscience decisions, the expert system TIME was developed (9: p.93). Using a database of common construction activities and user supplied project information, TIME compiles a list of activities with dependencies, durations, and costs. This list is then used to create estimated project costs and duration.

3.2.4 Equipment Optimization

Proper selection and optimization of construction equipment can determine the success or failure of large earthmoving projects. While optimization can be accomplished by simulation and economic analysis, actual selection of an earthmoving strategy is often based on field experience and rules of thumb. This selection is influenced by factors such as equipment availability and personal preference as well as project site conditions. The knowledge involved in such decisions has been cloned by several expert systems.

One such system, ESEMPS, can select appropriate equipment combinations as well as optimizing the earthmoving operation (14: p.426). The system first solicits project information from the user. One piece of information required, the volume of the excavation, could be provided automatically from CAD drawings as previously discussed. With necessary information gathered, the system proceeds to select the appropriate equipment category (such as scraper, dozer, or loader/truck) for the project. After selection of the appropriate equipment type, the system calculates production rates and costs for differing equipment models and combinations to determine the lowest cost and/or shortest duration project. This equipment combination is then recommended as the optimal solution.

A similar unnamed system was created that uses LOTUS 1-2-3 spreadsheets to perform the simulation and calculation portions of the program (15: p.224). EXSIM is another

equipment selection system that interfaces with simulation software to model possible equipment types and combinations (16: p.330).

A related expert system, CRANE, aids in the selection and positioning of tower cranes for construction projects (9: p.89 and 17: p.290). As with other systems, CRANE requests project information from the user to make its analysis. The system uses graphics to allow the user to describe the site configuration and identify anticipated crane loads and working radii. After determining the number of cranes required and the size and location of each, CRANE consults its database of available cranes to select an appropriate model. The system is intended to assist to expert and educate the novice user.

3.2.5 Project Site Layout

Since construction projects are typically built for ownership by someone other than the contractor, temporary facilities and equipment are necessary. Often required are buildings to support on-site personnel as well as facilities for material and equipment storage. These temporary facilities should be located to provide the most efficient working environment possible. But as is often the case, these facilities are arbitrarily placed and future inefficiencies such as increased travel time and facility relocation are likely to occur.

Because facility location is a multi-dimensional spatial arrangement problem which is not adequately addressed by

existing rule based systems, a specialized development architecture called ACCORD was used. ACCORD has the special ability to solve problems involving the assembly of objects under given constraints. Using ACCORD, an expert system called SIGHTPLAN was developed to aid planners in the layout of temporary facilities on construction sites (9: p.90).

3.2.6 Site Safety

Construction safety is a primary concern to contractors and owners alike. Safety is such a great concern that The Business Roundtable has recommended that a contractor's expected safety performance be used as a criteria for contractor selection. To allow owners and contractors to easily evaluate safety performance, a pair of safety oriented expert systems have been developed.

SAFEQUAL is geared towards the owner and provides an analysis of expected safety performance. The system is rooted in the work done by The Business Roundtable and even uses the questionnaire that was developed during their study. The owner uses the questionnaire to survey all prospective contractors and SAFEQUAL evaluates the contractor's responses to determine which contractors should be considered for contract award. SAFEQUAL was placed on the market in 1987 as an off-the-shelf construction management product (9: p.96).

HOWSAFE is a related expert system that allows contractors to perform an evaluation of their own operations (9: p.99). The system represents knowledge in an inverted

logic tree that starts the user at the bottom "leaf" nodes and allows progress up the tree. The user's responses to the leaf node questions are combined and evaluated to provide a hypothesis about the general condition of the company's safety program. SAFEQUAL and HOWSAFE were both developed at Stanford University and are distributed by Building Systems, Incorporated.

3.2.7 Contract Administration

A number of other construction management expert systems have been developed that fall into general support category. The topics are varied but each system provides expertise to the construction manager for day-to-day project management. The systems are discussed in their natural order of progression from project concept through the construction process.

Since uncertainties can arise at any point in a construction project, it behooves managers to identify possible risks and determine appropriate countermeasures. IRIS is a risk management system that assists construction managers in risk identification and analysis (18: p.307). The system incorporates an extensive list of potential risks collected from experienced construction personnel and other experts in the field. The system interfaces with a database management software for data storage and a graphics program for system graphics.

Since most construction projects are performed under contract, construction managers must also be adept contract administrators. A variety of contracting options are available and project owners need the expertise to select the appropriate contract type. PROPICK is an expert system that provides the expertise to make that selection based on cost, schedule, and project flexibility (9: p.96). Owners determine which factors are most important for the project and the system recommends a contracting strategy as well as a pricing mechanism. The system is fully operational and is being expanded to cover other areas of construction management.

Construction contractors are often faced with a wide assortment of projects on which to bid. Contractors must consider the type of work, the owners reputation, and their own experience and present workload when deciding on which projects to bid. After deciding to bid a project, contractors must determine an appropriate markup considering the risks involved. BIDEX is a system developed to aid the contractor in these decisions (19: p.160). The system knowledge is based on a survey of construction experts and contractors. Rules in the first part of the system (bid/no bid) are highly knowledge oriented while rules in the second part (markup determination) are largely computational. BIDEX has an extensive explanation facility and the user may query the system to determine the relevance of questions.

Owners are often dealing with unfamiliar contractors when bidding or negotiating their contracts. Many selective owners are using a prequalification strategy to determine the contractors with whom they will deal. Prequalification is a process of determining a contractor's competence and ability to accomplish a given type of project. QUALIFIER-1 provides owners with the ability to preform a structured, systematic, and rational approach to contractor prequalification (20: p.77).

The system is based on a survey of nearly 200 construction professionals and their views on 20 different evaluation factors. The factors include topics such as financial stability, past experience and performance, professional references, and bonding capacity. Based on user input, the system calculates an aggregate weighting factor which is used to determine relative ranking of contractors. QUALIFIER-1 does require the user to analyze contractor submitted information and generate a numerical rating for each factor. The system is limited to number manipulation and data processing making it computational in nature.

After receiving a contract award, the contractor's first move is to organize a construction team to control the project. To help managers evaluate existing organizations for use on future projects, an expert system called CPO-ES was developed (18: p.305). CPO was designed to systematize some of the planning processes for construction project

organization. It assists upper level management in analyzing current project organizations, finding ways to improve them, and retaining some of the project management expertise in the company. The system questions the user regarding organization goals and subgoals and the user responds with numerical ratings. After the question and answer period, the system will provide comments regarding the strengths and weaknesses of the organization being evaluated.

With every contract comes the strong possibility of disagreements between the contracting parties. The construction industry is no exception and construction contracts are often complicated by claims. Since on-site personnel are usually not too familiar with the legal implications of contract claims, expert legal advice is often necessary. Construction managers are often hesitant to call for legal assistance and usually wait until the situation becomes a major problem. Managers fail to realize that a short legal consultation during the initial phase of a disagreement can often save time and money by solving the problem as soon as possible.

To give construction managers an in house source of legal expertise, expert systems can be developed to address typical problems. These systems serve to educate novice managers while assisting the more experienced personnel. The Claims Guidance System (CGS) is one such expert system that is being developed for the U. S. Army Corps of Engineers (21: p.68).

The system will analyze construction contract claims that arise from many different areas of the contract. The system is being developed in a modular nature so that each module will operate independently.

The first module is CGS-DCS which deals with claims based on the differing site conditions clause in many construction contracts. The clause allows contractors to request additional payment when site conditions differ from what would normally be expected to exist. This module provides an insight into the legal implications of the clause and determines the contractor's entitlement to additional payment. The DCS module is operational and is undergoing field testing. A second module covering the contract changes clause is currently under development.

3.3 Problems with Expert Systems in Construction

The expert system may initially appear to have the capability to solve the problems of the construction industry. On closer investigation, it is clear that expert systems may never become an all knowing expert in the construction management field. Construction management problems are so diverse and the span of knowledge is so great that a single construction management system is impractical. Expert systems also lack the key ingredient necessary to solve many construction management problems; namely, common sense.

While expert systems do lack common sense and may not be able to solve all manner of problems on a project site, they

definitely have a role in construction management. Expert systems can be invaluable aids for the construction manager by attacking the more time consuming and rarely encountered problems.

While potential applications for expert systems abound in the field of construction management, few operational systems currently exist. The construction industry is generally considered to be conservative and, as such, is unwilling to adopt new technology. If expert systems are to become commonplace in the industry, the conservativeness of the industry and the general fear of computers and artificial intelligence must be overcome. Managers must be convinced that these systems are meant to aid and assist them, not to replace them. This can best be done by slowly integrating expert systems into commonly computerized applications such as scheduling and estimating. These early introductory applications should be user friendly to gain the confidence of users. Only then can more powerful systems be introduced in project planning, legal guidance, and other innovative areas.

3.4 The Future of Expert Systems in Construction

Considering that the construction industry is conservative in nature, it is surprising to discover the amount of work that has already been done on researching expert systems in construction management. Expert systems are considered by many to offer potentially valuable capabilities to support decision making in the industry (9: p.107). Expert

systems in other areas of business and industry report savings of tens of millions of dollars per year giving returns on investment in the thousands of percent (21: p.75). With this magnitude of potential savings, expert systems warrant further investigation and development.

According to Maher (9: p.110), the future of expert systems in construction management rests in ongoing research in two different fields. The first field is compatibility with existing software and programs. Systems that provide a sophisticated front end to database programs or scheduling and estimating packages should be marketable at this time. They could serve to introduce the industry to expert systems at the field level while providing expertise to existing programs. Second, systems with abilities to extract design information from CAD programs will drive the next wave of automated planning, estimating, and scheduling software. While this may be a number of years away from reality, it will likely be the breakthrough that will sell the construction industry on expert systems.

CHAPTER FOUR
DEVELOPMENT OF AN EXPERT SYSTEM FOR EQUIPMENT SELECTION

4.1 Introduction

As discussed in chapter three, a wide variety of expert systems have been developed in many different areas of construction management. To better understand the procedures involved in system development, an expert system was developed as part of this report. The system is called Construction Equipment Selector (CES) and was developed on Personal Consultant Easy (PC Easy), an expert system shell marketed by Texas Instruments. The goal of CES is to recommend the appropriate type and model of equipment based on the type of earthmoving project and site conditions anticipated. CES also suggests any additional supporting equipment required. The system interfaces with dBASE III+ database management software for model selection from a database of available equipment.

4.2 Task Selection

With the wide variety of potential applications for expert systems in construction management, selection of a narrow system task is difficult. The project planning process was initially considered, but since CAD interface technology is still under development, any work in this area would be limited. Development of an expert system in either estimating or scheduling was also considered. Since an expert system in either of these fields would primarily serve as a sophisticated front end for existing software, another alternative was desirable. Because of its knowledge intensive

nature, selection of construction equipment was the next alternative considered. Equipment selection is primarily based on type of project, appropriate rules of thumb, and equipment economics. Since a limited scope and deep knowledge make it especially suitable for expert system technology, the equipment selection task was incorporated into an expert system called the Construction Equipment Selector (CES).

4.3 Equipment Selection Logic

Selection of construction equipment is made by considering the type of excavation project, appropriate rules of thumb, and the economics of individual models of equipment. CES recommends equipment type and model based on those three factors. CES first determines appropriate equipment types based on the type of project. Equipment capabilities and rules of thumb are then used to recommend the most appropriate type of equipment plus any necessary supporting equipment. Finally, capabilities and operating costs of available equipment models are considered and a particular model is recommended to the user.

CES divides earthmoving projects into four major categories from which the user may select. These categories are:

A) Trench or canal construction

B) Basement excavation

C) Vertical shaft excavation

D) Cut and fill operation

Since each type of proje·' is best performed by one or more equipment types, CES uses the logic described in the following paragraphs to determine a specific equipment type and model.

CES is capable of recommending eight different types of equipment. Except for auger equipment, all equipment types also include databases of available models. Model selection is based on different criteria for the different types of equipment and is discussed below. Appendix A presents the information contained in the equipment model d- abases.

When the user selects a trench or canal project, CES considers trenchers and backhoes as appropriate. Trenchers are preferred over backhoes and are recommended when the depth and width of the trench allow. If neither type of equipment is physically capable of performing the project CES will refer the user to a cut and fill operation. When ground conditions require it, crawler mounted models are recommended. Figure 4 shows the logic used for equipment selection when the user selects a trench or canal project.

Since trencher production is difficult to predict, trenchers are recommended according the lowest hourly cost of all models capable of performing the work (22: p.9-1 and 23: p.59). Similar to trencher selection, backhoe selection is based on the model with the lowest cost per unit excavation among the models capable of performing the project. Unit cost is based on typical cycle times (24: p.41), bucket capacities (25: p.6), and hourly cost (22: p.9-57, 10-6, and 10-16).

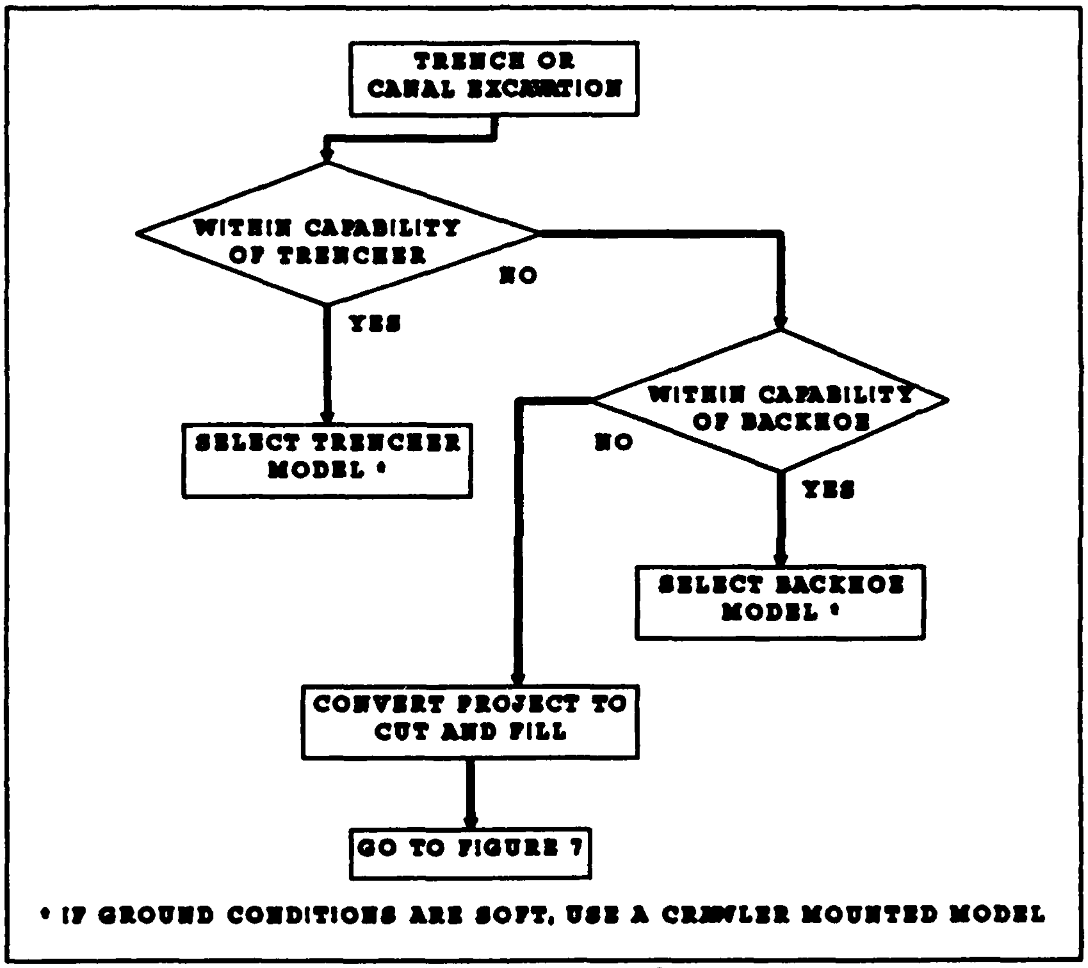

Figure 4. Logic for trench or canal project

Basement excavation projects are generally performed by backhoes or shovels. The backhoe is preferred and is recommended when it has the digging ability to perform the project and when adequate room exists along the perimeter of the excavation. Otherwise, a shovel is recommended and, like the backhoe, a model is selected based on cost per unit excavation. Shovel production unit costs are based on ideal productivity under differing conditions (24: p.30) and hourly costs (22: p.10-6 and 10-16). Figure 5 shows the logic used

to select equipment type and model for basement excavation projects.

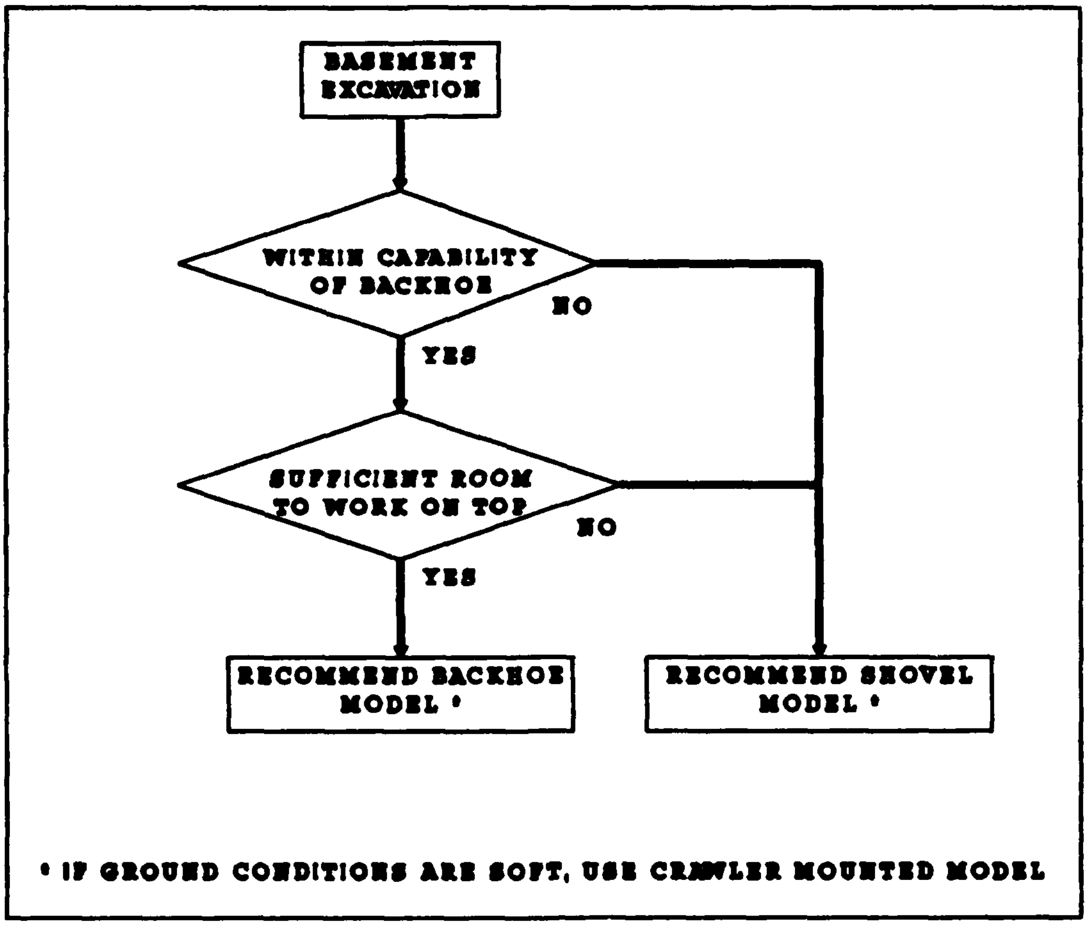

Figure 5. Logic for basement excavation project

If the project involves excavation of a vertical shaft or tunnel, CES recommends an auger where appropriate or a clamshell equipped crane if an auger is inappropriate. Crawler mounted equipment is recommended as required. Due to the wide variety of auger and clamshell equipment available, no specific models are included in CES. Figure 6 shows the logic used to select between auger and clamshell equipment.

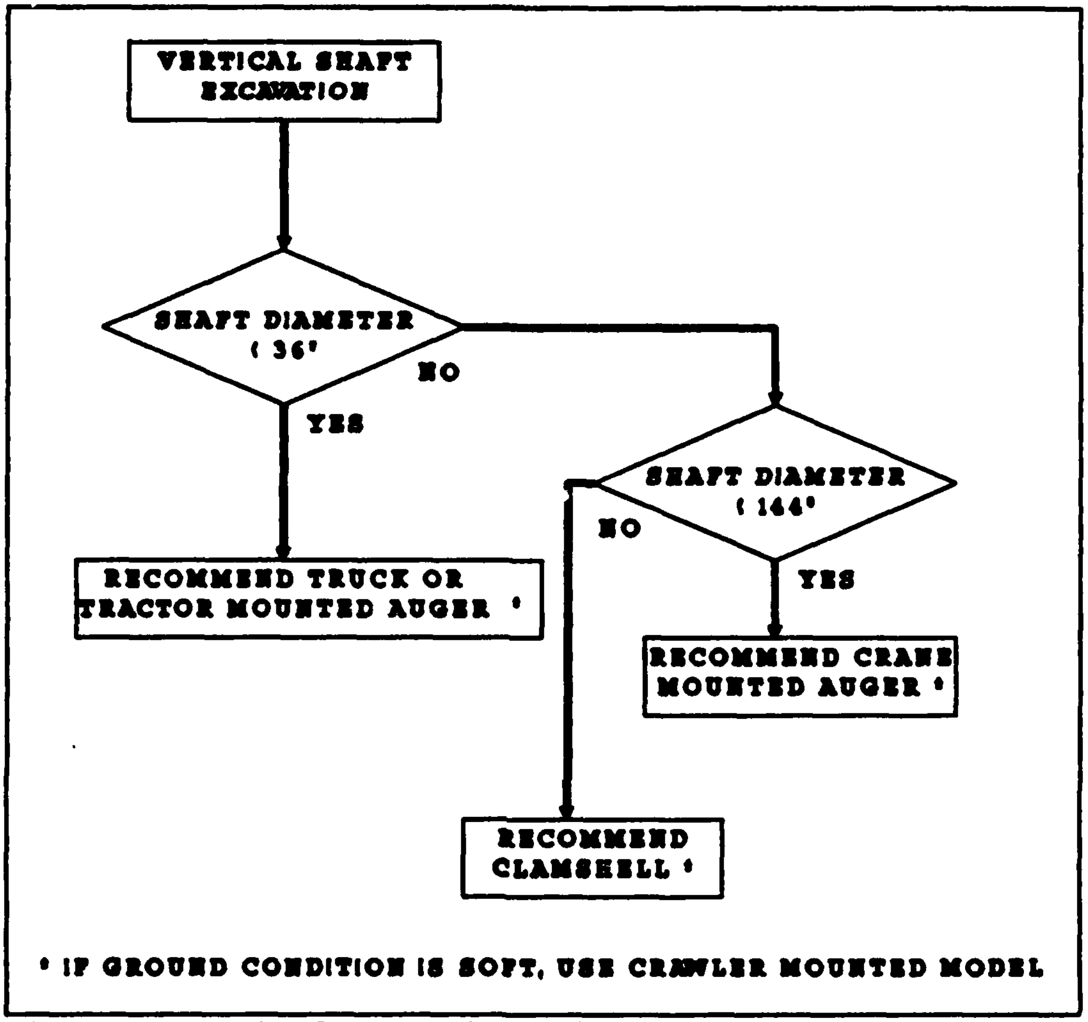

Figure 6. Logic for vertical shaft project

The final project category of cut and fill operation encompasses many general earthmoving projects. Under this category, CES recommends that the project be performed by either dozers, scrapers, or shovels. Dozer models are selected based on cost per unit excavation which is calculated from productivity at various haul distances (26: p.58) and hourly cost (22: p.9-134). Crawler mounted dozers are recommended as required by ground conditions. Scraper models are likewise selected based on cost per unit excavation which is calculated

from scraper capacity and hourly cost (22: p.9-123). Figure 7 shows the logic used to recommend equipment type and model for cut and fill operations.

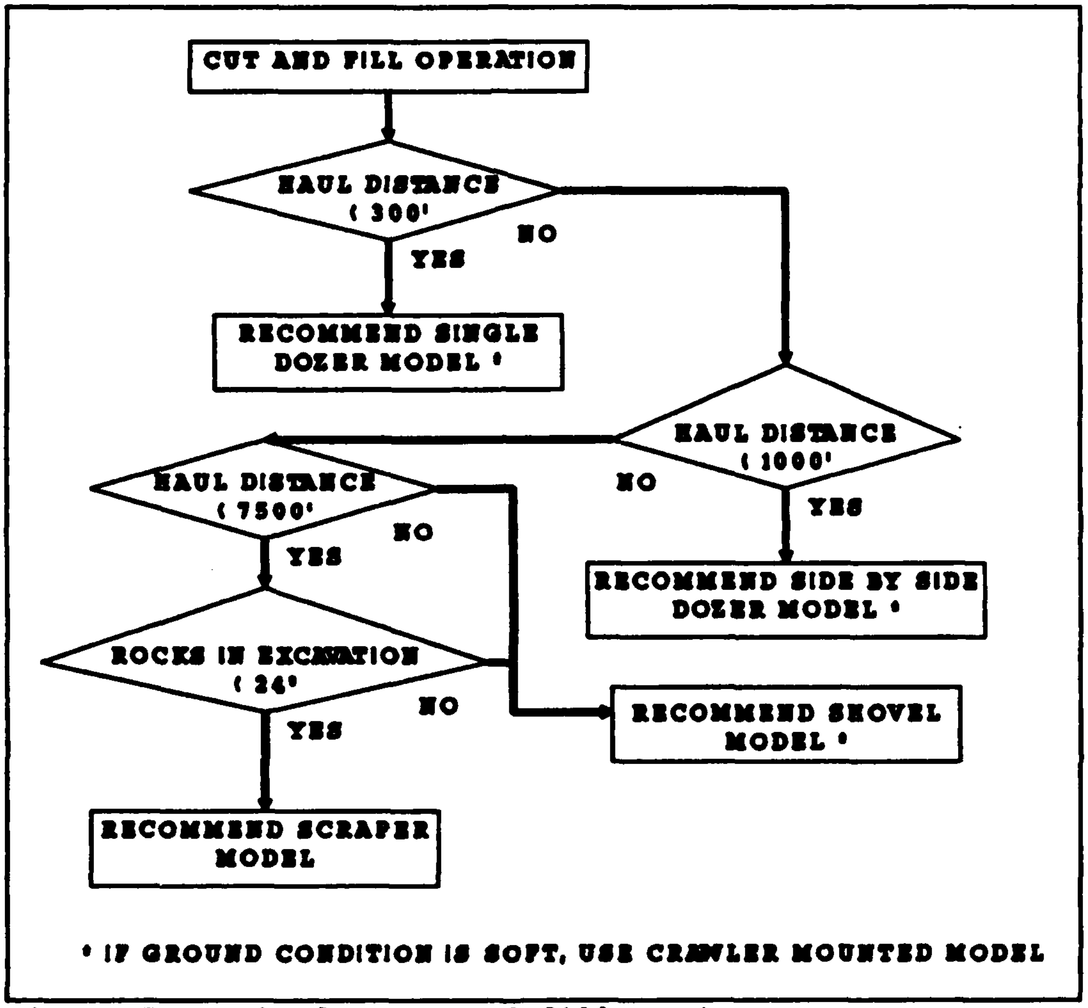

Figure 7. Logic for cut and fill project

4.4 System Development

As discussed in chapter two, development of an expert system begins with selection of an appropriate task. The task should be suitable for expert system technology and as such must be knowledge oriented and narrow in scope. As discussed

above, the task of equipment selection was chosen and CES was subsequently developed.

The next two steps of determining who would develop the system and what programming environment to use were easily accomplished. Since CES was developed as part of this report, system development would logically be in house. Because of its availability and ease of use, PC Easy was used as the system development environment.

The next step of conceptualizing the system requirements helped determine the overall intent of the program. System scope was further defined and alternative methods of accomplishing the intent were investigated. With the scope well defined, the goals of the system could then be formalized. Since CES is an equipment selection expert system, the logical goals are equipment type and model. To further aid the user, another goal of additional support equipment was included. With these three goals established, system implementation began.

The implementation phase of system development required the formulation of the equipment selection logic discussed above. With this logic established, the expert system was then programmed in PC Easy. This process began by entering and defining the three goals. Next, the equipment selection logic was converted into a series of if-then rules that were used to create the system knowledge base. As the if-then rules were entered, parameters that are used to select between

alternative equipment (such as basement depth or trench width) were defined. Finally, after development was completed, the system was tried and debugged as necessary. Appendix B is a listing of the goals, parameters, and rules of which CES is comprised.

Since CES was developed as an educational exercise, it is limited in its abilities. CES could be broadened in scope to include other types of projects in construction. The databases of equipment models could be expanded to include additional equipment manufacturers (only Caterpillar, Ditch Witch, and Capitol Trencher are included). The system could include routines to determine appropriate numbers of equipment as well as more detail on numbers, types, and models of supporting equipment (such as trucks serving shovels). However, CES does serve to demonstrate the potential of expert systems in construction management.

4.5 A Sample Consultation with CES

For demonstration purposes, a sample consultation with CES is presented. Statements preceded by CES are prompts provided by CES and statements preceded by USER are the replies provided by the user.

CES: The CONSTRUCTION EQUIPMENT SELECTOR is an expert system that will determine the appropriate type and model of equipment that you should use for your particular earthmoving project.

USER: Presses return to continue.

CES: From the list below, select the type of earthmoving project that most closely resembles your project.

TRENCH/CANAL
BASEMENT
VERTICAL SHAFT
CUT AND FILL EARTHMOVING

USER: Selects basement.

CES: Is the condition of the site extremely soft or mushy?

YES
NO

USER: Selects no.

CES: What is the depth of the basement being excavated? Round up to the nearest foot.

USER: Enters 20.

CES: Is there sufficient room at the site to excavate the basement from ground level?

YES
NO

USER: Selects yes.

At this point, CES has decided to recommend a backhoe for the basement excavation. CES now calls on a dBASE III+ database file to select the appropriate model. For a backhoe, the selection is made on the basis of digging depth, crawler mounting (because of poor ground conditions), and cost per unit excavation.

CES CONCLUSIONS:

The type of construction equipment that you should use for your project is as follows: Backhoe

The model of the equipment that is recommended is as follows: Caterpillar 225 (1.25CY)

Any other required support equipment is as follows: Sufficient trucks to remove excavation as required. Trucks should have a capacity of at least four bucket loads and the capacity should be a multiple of the bucket size for maximum efficiency.

This sample consultation is only one of many that are possible with CES. CES considers four different project types and can recommend eight different types of equipment. Several equipment types are further divided into different equipment configurations and most equipment types include a variety of models that may be recommended. The number of possible outcomes is considerable, even for a small expert system like CES.

CHAPTER FIVE
SUMMARY AND RECOMMENDATIONS

5.1 Summary of Expert Systems in Construction Management

With expert systems still clouded in a vail of mystery, only researchers and the boldest of construction professionals are considering the expert system as a potential part of the construction management system. The roles of the expert system in construction management are, therefore, only beginning to be uncovered. Microcomputers, which are generally relegated to number crunching tasks, hold the power to run sophisticated expert systems. These microcomputer based expert systems could become invaluable tools for construction managers in either the field or home office environment.

While expert system research in the area of construction management is substantial, it is largely academic in nature. It appears as though the expert system is the latest toy in construction management research and everyone wants to play. The problem is that very few of the operational systems actually reach the field level for which they are intended. Researchers must turn their efforts towards practical, field oriented systems that the industry can use as an icebreaker for the more powerful systems that could be developed.

Expert systems have been developed for a wide variety of applications. Systems that upgrade existing scheduling and estimating represent a potentially marketable product. These types of systems could serve to sell the industry on the

concept of expert systems. After the industry is somewhat comfortable with the concept, systems for equipment selection and optimization, equipment location, and temporary facility layout could be introduced. With a gradual introduction and a through understanding of expert systems, the construction industry will then be primed to accept truly revolutionary systems such as automated planning.

When considering any investment in expert systems, developers and users must remember that system limitations do exist. Cloning the human expert is a difficult task and the resulting system is limited to the skills of the development team. Most expert systems have little learning ability and are often unable to fully explain the reasoning used to reach their conclusions. Even with these inherent limitations, the expert system can function quite well in the role of advisor or assistant to the construction professional.

In addition to the limitations, users must consider the justification for use of expert system technology. The task selected for system development should have a high payoff (financial or otherwise) to offset the investment. Human experts should be unavailable or should be unable to easily perform the task. When loss of existing human expertise is a problem, that expertise can be retained in the form of an expert system.

Finally, users must consider the legal implications of using or not using expert systems. Software companies and

system developers risk exposure to liability by creating an expert system. Users also bear the risk of liability based on unreasonable reliance on system provided information. Although it is not likely in the near future, potential users may also be held liable for failure to use available expert systems. These legal implications only serve to complicate the introduction of expert system technology.

5.2 Recommendations for Future Research

The future of expert system development rests on two primary factors. The first is compatibility with existing software and programs. Companies are unwilling to invest in technology that is unable to interface with the companies' existing systems. The second key factor is interface with and expansion of CAD capabilities. Practical communication between CAD and expert systems will clear the way for total construction planning, scheduling, and estimating systems. Any additional research in the area of CAD interface can only benefit the future of expert systems.

In addition, planning, scheduling, estimating, equipment optimization, site layout, safety, and contract administration would all be prime topics for research at the university level. Because of the broad scope of this paper, potential areas of application were only summarized. In depth analysis of a single application plus development of an operational expert system would provide a challenging opportunity for graduate level study. Research into potential new

applications would also be of great benefit for the construction industry. The greatest benefit of all would come from development of operational expert systems that can be delivered to the field. The construction industry realizes little benefit from conceptual and prototype systems that never reach their intended users.

APPENDIX A

EQUIPMENT MODEL DATABASES

The following dBASE III+ reports show the information contained in the equipment model files. PC Easy selects an equipment model from these files when running CES. Cost information contained in these reports is NOT actual but is included for comparison between models.

DATABASE OF SHOVEL EQUIPMENT MODELS

EQUIPMENT MANUFACTURER AND MODEL	MATERIAL CONDITION	COST PER UNIT EXCAVATION ($/CY)	CRAWLER MOUNTED
Caterpillar 235 (3CY)	HARD	19	YES
Caterpillar 245 (4CY)	SOFT	24	YES
Caterpillar 245 (4CY)	HARD	25	YES
Caterpillar E650 (5CY)	HARD	26	YES
Caterpillar 245 (4CY)	MEDIUM	32	YES
Caterpillar 235 (3CY)	MEDIUM	33	YES
Caterpillar E650 (5CY)	MEDIUM	34	YES
Caterpillar E650 (5CY)	SOFT	36	YES
Caterpillar 235 (3CY)	SOFT	37	YES

DATABASE OF BACKHOE EQUIPMENT MODELS

EQUIPMENT MANUFACTURER AND MODEL	MAX DIGGING DEPTH (FT)	COST PER UNIT EXCAVATION ($/CY)	CRAWLER MOUNTED
Caterpillar 428 (1.35CY)	18	17	NO
Caterpillar 436 (1.38CY)	16	17	NO
Caterpillar 426 (1.25CY)	15	18	NO
Caterpillar 416 (1CY)	14	20	NO
Caterpillar 446 (1.5CY)	17	22	NO
Caterpillar 225 (1.25CY)	22	40	YES
Caterpillar E240 (1.25CY)	23	41	YES
Caterpillar 205 (.68CY)	16	42	YES
Caterpillar E300 (1.5CY)	26	43	YES
Caterpillar E180 (1CY)	20	43	YES
Caterpillar 229 (1.5CY)	21	45	YES
Caterpillar 214 (.95CY)	17	46	NO
Caterpillar 206 (.68CY)	16	46	NO
Caterpillar 245 (3.125CY)	35	46	YES
Caterpillar 212 (.84CY)	17	47	NO
Caterpillar 215 (1CY)	19	50	YES
Caterpillar 211 (.68CY)	18	50	YES
Caterpillar 235 (2CY)	27	60	YES
Caterpillar 224 (.91CY)	19	63	NO
Caterpillar 213 (.32CY)	17	114	YES

DATABASE OF TRENCHER EQUIPMENT MODELS

EQUIPMENT MANUFACTURER AND MODEL	MAX (FT) DEPTH	MAX (FT) WIDTH	COST PER HOUR ($)	CRAWLER MOUNTED
Ditch Witch C99	2	6	1	NO
Ditch Witch 1410	5	12	2	NO
Ditch Witch 2020	5	16	4	NO
Ditch Witch 3210	6	18	6	NO
Ditch Witch 4010	7	24	7	NO
Ditch Witch R100	8	24	17	NO
Capitol Trencher 350	3	24	23	YES
Capitol Trencher 450	4	24	27	YES
Capitol Trencher 550	5	24	34	YES
Capitol Trencher 650	6	28	37	YES
Capitol Trencher 750	7	36	50	YES
Capitol Trencher 810	15	48	62	YES
Capitol Trencher 850	8	48	77	YES
Capitol Trencher 950	9	72	97	YES
Capitol Trencher 830	7	72	100	YES
Capitol Trencher 960	9	42	116	YES
Capitol Trencher 910	25	60	118	YES
Capitol Trencher 1050	10	84	137	YES

DATABASE OF SCRAPER EQUIPMENT MODELS

SECS = SINGLE ENGINE CONVENTIONAL SCRAPER, SEES = SINGLE ENGINE ELEVATING SCRAPER, TECS = TWIN ENGINE CONVENTIONAL SCRAPER, AND TEAE = TWIN ENGINE AUGER EQUIPPED

EQUIPMENT MANUFACTURER AND MODEL	SCRAPER TYPE	COST PER UNIT EXCAVATION ($/CY)
Caterpillar 651	SECS	441
Caterpillar 621	SECS	475
Caterpillar 631	TEAE	503
Caterpillar 631	SECS	503
Caterpillar 613	SEES	505
Caterpillar 623	SEES	515
Caterpillar 615	SEES	521
Caterpillar 657	TECS	543
Caterpillar 657	TEAE	543
Caterpillar 627	TEAE	565
Caterpillar 627	TECS	565
Caterpillar 637	TECS	621
Caterpillar 637	TEAE	621

DATABASE OF DOZER EQUIPMENT MODELS

EQUIPMENT MANUFACTURER AND MODEL	HAULING DIST (FT)	COST PER UNIT EXCAVATION ($/CY)	CRAWLER MOUNTED
Caterpillar 814	100	5	NO
Caterpillar 824	100	6	NO
Caterpillar 834	100	7	NO
Caterpillar D11	100	8	YES
Caterpillar D10	100	9	YES
Caterpillar D9	100	11	YES
Caterpillar D8	100	12	YES
Caterpillar D5	100	13	YES
Caterpillar 824	200	13	NO
Caterpillar D7	100	14	YES
Caterpillar D6	100	14	YES
Caterpillar D4	100	14	YES
Caterpillar 834	200	14	NO
Caterpillar 814	200	15	NO
Caterpillar D10	200	16	YES
Caterpillar D11	200	17	YES
Caterpillar 834	300	18	NO
Caterpillar 824	300	19	NO
Caterpillar D9	200	19	YES
Caterpillar D3	100	20	YES
Caterpillar 814	300	20	NO
Caterpillar D8	200	21	YES
Caterpillar D10	300	22	YES

DATABASE OF DOZER EQUIPMENT MODELS

EQUIPMENT MANUFACTURER AND MODEL	HAULING DIST (FT)	COST PER UNIT EXCAVATION ($/CY)	CRAWLER MOUNTED
Caterpillar D11	300	24	YES
Caterpillar D6	200	25	YES
Caterpillar D5	200	25	YES
Caterpillar D4	200	27	YES
Caterpillar D9	300	27	YES
Caterpillar D8	300	31	YES
Caterpillar D7	300	36	YES
Caterpillar D6	300	38	YES
Caterpillar D3	200	41	YES
Caterpillar D5	300	44	YES
Caterpillar D3	300	53	YES
Caterpillar D4	300	54	YES

APPENDIX B

CES GOALS, PARAMETERS, AND RULES

The following report shows the PC Easy goals, parameters, and rules for the CES expert system. PC Easy uses this information to solve construction equipment selection problems.

```
DOMAIN :: "CONSTRUCTION EQUIPMENT SELECTOR"

====================
   Global KB data
====================

  GOALS :: EQUIPMENT MODEL OTHER

  INITIALDATA :: PROJECT GROUND

  PROMPTEVER :: The CONSTRUCTION EQUIPMENT SELECTOR is an
  expert system that will determine the appropriate type and
  model of equipment that you should use for your particular
  earthmoving project.

  DISPLAYRESULTS :: YES

  PARAMETERS :: BASEMENT-DEPTH DISTANCE EQUIPMENT GROUND
  LEVEL MATERIAL MODEL OTHER PROJECT ROCKS SHAFT-DIAMETER
  TRENCH-DEPTH TRENCH-WIDTH

  RULEGROUPS :: KB-RULES
  KB-RULES :: RULE001 RULE002 RULE003 RULE004 RULE005 RULE006
  RULE007 RULE008 RULE009 RULE010 RULE011 RULE012 RULE013
  RULE014 RULE015 RULE016 RULE017 RULE018 RULE019 RULE020
  RULE021 RULE022 RULE023 RULE024 RULE025 RULE026 RULE027
  RULE028 RULE029 RULE030 RULE031 RULE032 RULE033 RULE034
  RULE035 RULE036 RULE037 RULE038
  NUMBER OF RULES :: 38


================
   Parameters
================


  BASEMENT-DEPTH
  ==============
  TRANSLATION :: depth of the basement
  PROMPT :: What is the depth of the basement being
  excavated? Round up to the nearest foot.
  TYPE :: SINGLEVALUED
  EXPECT :: POSITIVE-NUMBER
  CONTAINED-IN :: RULE037 RULE038
  USED-BY :: RULE013 RULE014

DISTANCE
========
  TRANSLATION :: haul distance
  PROMPT :: What is the distance that the excavated material
  must be moved? Round up to the nearest foot.
  TYPE :: SINGLEVALUED
```

EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: RULE026 RULE027 RULE028 RULE029 RULE030
RULE031 RULE021 RULE020 RULE022 RULE023
USED-BY :: RULE016 RULE017 RULE018 RULE019

EQUIPMENT
=========
TRANSLATION :: the type and model of construction equipment
that you should use for your project
TYPE :: SINGLEVALUED
ANTECEDENT-IN :: RULE009 RULE025 RULE026 RULE027 RULE028
RULE029 RULE030 RULE031 RULE032 RULE033 RULE010 RULE024
RULE037 RULE038 RULE036 RULE035 RULE034
USED-BY :: RULE011 RULE012
UPDATED-BY :: RULE001 RULE006 RULE007 RULE008 RULE002
RULE003 RULE004 RULE005 RULE016 RULE017 RULE013 RULE014
RULE018 RULE019
UPDATED-IN :: RULE021 RULE020 RULE022 RULE023

GROUND
======
TRANSLATION :: condition of the ground
PROMPT :: Is the condition of the site extremely soft and
mushy?
TYPE :: YES/NO
ANTECEDENT-IN :: RULE009 RULE025 RULE026 RULE027 RULE028
RULE029 RULE030 RULE031 RULE032 RULE033 RULE021 RULE020
RULE022 RULE023 RULE010 RULE024 RULE037 RULE038
USED-BY :: RULE011 RULE012

LEVEL
=====
TRANSLATION :: level of excavation
PROMPT :: Is there sufficient room at the site to excavate
the basement from ground level?
TYPE :: YES/NO
USED-BY :: RULE013 RULE014

MATERIAL
========
TRANSLATION :: type of material being excavated
PROMPT :: From the list below, select the type of material
to be excavated.
TYPE :: SINGLEVALUED
EXPECT :: HARD MEDIUM SOFT
ANTECEDENT-IN :: RULE036 RULE035 RULE034
USED-BY :: RULE014 RULE018 RULE019

MODEL
=====
TRANSLATION :: the model of the equipment that is recommended
TYPE :: SINGLEVALUED
CONTAINED-IN :: RULE009 RULE025 RULE026 RULE027 RULE028 RULE029 RULE030 RULE031 RULE032 RULE033 RULE021 RULE020 RULE022 RULE023 RULE010 RULE024 RULE037 RULE038 RULE036 RULE035 RULE034
UPDATED-BY :: RULE011 RULE012

OTHER
=====
TRANSLATION :: any other required support equipment
TYPE :: SINGLEVALUED
UPDATED-BY :: RULE002 RULE003 RULE004 RULE016 RULE017 RULE014 RULE018 RULE019
UPDATED-IN :: RULE009 RULE025 RULE021 RULE020 RULE022 RULE023 RULE010 RULE024 RULE037 RULE038

PROJECT
=======
TRANSLATION :: type of earthmoving project
PROMPT :: From the list below, select the type of earthmoving project that most closely resembles your project.
TYPE :: SINGLEVALUED
EXPECT :: TRENCH/CANAL BASEMENT VERTICAL-SHAFT CUT-AND-FILL-EARTHMOVING
ANTECEDENT-IN :: RULE021 RULE020 RULE022 RULE023 RULE010 RULE024 RULE037 RULE038 SREFMARK RULE015
USED-BY :: RULE001 RULE006 RULE007 RULE008 RULE002 RULE003 RULE004 RULE005 RULE016 RULE017 RULE013 RULE014 RULE018 RULE019
UPDATED-IN :: SREFMARK RULE015

ROCKS
=====
TRANSLATION :: diameter of rocks in the excavation
PROMPT :: What is the diameter of the largest rocks expected in the excavation? Round up to the nearest inch.
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: RULE021 RULE020 RULE022 RULE023
USED-BY :: RULE019

```
SHAFT-DIAMETER
==============
  TRANSLATION :: diameter of the vertical shaft
  PROMPT :: What is the diameter of the vertical shaft? Round
  up to the nearest inch.
  TYPE :: SINGLEVALUED
  EXPECT :: POSITIVE-NUMBER
  USED-BY :: RULE002 RULE003 RULE004

TRENCH-DEPTH
============
  TRANSLATION :: depth of the trench
  PROMPT :: What is the depth of your trench? Please round up
  to the next whole foot.
  TYPE :: SINGLEVALUED
  EXPECT :: POSITIVE-NUMBER
  CONTAINED-IN :: RULE009 RULE025 RULE010 RULE024
  ANTECEDENT-IN :: SREFMARK RULE015
  USED-BY :: RULE001 RULE006 RULE007 RULE008 RULE005

TRENCH-WIDTH
============
  TRANSLATION :: width of the trench
  PROMPT :: What is the width of your trench? Please round up
  to the next whole inch.
  TYPE :: SINGLEVALUED
  EXPECT :: POSITIVE-NUMBER
  CONTAINED-IN :: RULE009 RULE025
  USED-BY :: RULE001 RULE006 RULE007 RULE008


==============
   KB-RULES
==============


RULE001
=======
If   1) type of earthmoving project is TRENCH/CANAL, and
     2) width of the trench is less than or equal to 84, and
     3) depth of the trench is less than or equal to 10,
Then it is definite (100%) that the type and model of
     construction equipment
     that you should use for your project is Trencher.


RULE002
=======
If   1) type of earthmoving project is VERTICAL-SHAFT, and
     2) diameter of the vertical shaft is greater than 36,
     and 3) diameter of the vertical shaft is less than or
     equal to 144,
```

Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Crane mounted auger,
and 2) it is definite (100%) that any other required support equipment is None required.

RULE003
=======
If 1) type of earthmoving project is VERTICAL-SHAFT, and
2) diameter of the vertical shaft is less than or equal to 36,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Truck or tractor mounted auger, and
2) it is definite (100%) that any other required support equipment is None required.

RULE004
=======
If 1) type of earthmoving project is VERTICAL-SHAFT, and
2) diameter of the vertical shaft is greater than 144,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Crane mounted clamshell, and
2) it is definite (100%) that any other required support equipment is Adequate trucks for excavation removal as required.

RULE005
=======
If 1) type of earthmoving project is TRENCH/CANAL, and
2) depth of the trench is greater than 25, and
3) depth of the trench is less than or equal to 35,
Then it is definite (100%) that the type and model of construction equipment that you should use for your project is Backhoe.

RULE006
=======
If 1) type of earthmoving project is TRENCH/CANAL, and
2) width of the trench is less than or equal to 60, and
3) depth of the trench is less than or equal to 25,
Then it is definite (100%) that the type and model of construction equipment that you should use for your project is Trencher.

RULE007
=======
If 1) type of earthmoving project is TRENCH/CANAL, and
2) width of the trench is greater than 84, and
3) depth of the trench is less than or equal to 35,
Then it is definite (100%) that the type and model of construction equipment that you should use for your project is Backhoe.

RULE008
=======
If 1) type of earthmoving project is TRENCH/CANAL, and
2) width of the trench is greater than 60, and
3) depth of the trench is greater than 25, and
4) depth of the trench is less than or equal to 35,
Then it is definite (100%) that the type and model of construction equipment that you should use for your project is Backhoe.

RULE009
=======
If 1) the type and model of construction equipment that you should use for your project is Trencher, and
2) condition of the ground,
Then 1) retrieve data base values for several parameters, and
2) it is definite (100%) that any other required support equipment is None required.

ANTECEDENT :: YES

RULE010
=======
If 1) the type and model of construction equipment that you should use for your project is Backhoe, and
2) condition of the ground, and
3) type of earthmoving project is TRENCH/CANAL,
Then 1) retrieve data base values for several parameters, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.

ANTECEDENT :: YES

RULE011
=======
```
If   1)  1) the type and model of construction equipment that
            you should use for your project is Truck or tractor
            mounted auger, or
            2) the type and model of construction equipment that
            you should use for your project is Crane mounted
            auger, or
            3) the type and model of construction equipment that
            you should use for your project is Crane mounted
            clamshell, and
     2) condition of the ground,
Then it is definite (100%) that the model of the equipment
     that is recommended is crawler mounted.
```

RULE012
=======
```
If   1)  1) the type and model of construction equipment that
            you should use for your project is Truck or tractor
            mounted auger, or
            2) the type and model of construction equipment that
            you should use for your project is Crane mounted
            auger, or
            3) the type and model of construction equipment that
            you should use for your project is Crane mounted
            clamshell, and
      2) condition of the ground is not true,
Then it is definite (100%) that the model of the equipment
     that is recommended is wheel or crawler mounted.
```

RULE013
=======
```
If   1) type of earthmoving project is BASEMENT, and
     2) depth of the basement is less than or equal to 30,
     and 3) level of excavation,
Then it is definite (100%) that the type and model of
     construction equipment that you should use for your
     project is Backhoe.
```

RULE014
=======
```
If   1) type of earthmoving project is BASEMENT, and
     2)  1) depth of the basement is greater than 30, or
         2) level of excavation is not true, and
     3) type of material being excavated is not  ,
```

Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Shovel, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.

RULE015
=======
If 1) type of earthmoving project is TRENCH/CANAL, and
2) depth of the trench is greater than 35,
Then it is definite (100%) that type of earthmoving project is CUT-AND-FILL-EARTHMOVING.

ANTECEDENT :: YES

RULE016
=======
If 1) type of earthmoving project is CUT-AND-FILL-EARTHMOVING, and
2) haul distance is less than or equal to 300,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Single dozer, and
2) it is definite (100%) that any other required support equipment is None required.

RULE017
=======
If 1) type of earthmoving project is CUT-AND-FILL-EARTHMOVING, and
2) haul distance is greater than 300, and
3) haul distance is less than or equal to 1000,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Side by side dozers,
and 2) it is definite (100%) that any other required support equipment is none required.

RULE018
=======
If 1) type of earthmoving project is CUT-AND-FILL-EARTHMOVING, and
2) haul distance is greater than 7500, and
3) type of material being excavated is not ,

Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Shovel, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.

RULE019
=======
If 1) type of earthmoving project is CUT-AND-FILL-EARTHMOVING, and
2) diameter of rocks in the excavation is greater than 24, and 3) haul distance is greater than 1000, and
4) haul distance is less than or equal to 7500, and
5) type of material being excavated is not ,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Shovel, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY. .

RULE020
=======
If 1) type of earthmoving project is CUT-AND-FILL-EARTHMOVING, and
2) haul distance is greater than 1000, and
3) haul distance is less than or equal to 7500, and
4) condition of the ground, and
5) diameter of rocks in the excavation is less than or equal to 24,
Then 1) it is definite (100%) that the type and model of construction equipment that you should use for your project is Twin engine conventional scraper, and
2) it is definite (100%) that any other required support equipment is none required, and
3) retrieve data base values for several parameters.

ANTECEDENT :: YES

```
RULE021
=======
If   1) type of earthmoving project is
        CUT-AND-FILL-EARTHMOVING, and
     2) haul distance is greater than 1000, and
     3) haul distance is less than or equal to 7500, and
     4) condition of the ground is not true, and
     5) diameter of rocks in the excavation is less than or
        equal to 24, and
     6) diameter of rocks in the excavation is greater than
        18,
Then 1) it is definite (100%) that the type and model of
        construction equipment that you should use for your
        project is single engine conventional scraper, and
     2) it is definite (100%) that any other required support
        equipment is Appropriate pusher dozers, and
     3) retrieve data base values for several parameters.

  ANTECEDENT :: YES

RULE022
=======
If   1) type of earthmoving project is
        CUT-AND-FILL-EARTHMOVING, and
     2) haul distance is greater than 1000, and
     3) haul distance is less than or equal to 7500, and
     4) condition of the ground is not true, and
     5) diameter of rocks in the excavation is less than or
        equal to 18, and
     6) diameter of rocks in the excavation is greater than
        12,
Then 1) it is definite (100%) that the type and model of
        construction equipment that you should use for your
        project is Twin engine auger equipped scraper, and
     2) it is definite (100%) that any other required support
        equipment is
           None required, and
     3) retrieve data base values for several parameters.

  ANTECEDENT :: YES

RULE023
=======
If   1) type of earthmoving project is
        CUT-AND-FILL-EARTHMOVING, and
     2) haul distance is greater than 1000, and
     3) haul distance is less than or equal to 7500, and
     4) condition of the ground is not true, and
     5) diameter of rocks in the excavation is less than or
        equal to 12,
```

```
Then 1) it is definite (100%) that the type and model of
     construction equipment that you should use for your
     project is Single engine elevating scraper, and
     2) it is definite (100%) that any other required support
     equipment is none required, and
     3) retrieve data base values for several parameters.

  ANTECEDENT :: YES

RULE024
=======
If   1) the type and model of construction equipment that you
     should use for your project is Backhoe, and
     2) condition of the ground is not true, and
     3) type of earthmoving project is TRENCH/CANAL,
Then 1) retrieve data base values for several parameters, and
     2) it is definite (100%) that any other required support
     equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS
     REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4
     BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF
     THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.


RULE025
=======
If   1) the type and model of construction equipment that you
     should use for your project is Trencher, and
     2) condition of the ground is not true,
Then 1) retrieve data base values for several parameters, and
     2) it is definite (100%) that any other required support
     equipment is None required.

  ANTECEDENT :: YES

RULE026
=======
If   1) the type and model of construction equipment that you
     should use for your project is Single dozer, and
     2) haul distance is less than or equal to 100, and
     3) condition of the ground,
Then retrieve data base values for several parameters.

  ANTECEDENT :: YES

RULE027
=======
If   1) the type and model of construction equipment that you
     should use for your project is Single dozer, and
     2) haul distance is less than or equal to 100, and
     3) condition of the ground is not true,
```

Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE028
=======
If 1) the type and model of construction equipment that you should use for your project is Single dozer, and
2) haul distance is greater than 100, and
3) haul distance is less than or equal to 300, and
4) condition of the ground,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE029
=======
If 1) the type and model of construction equipment that you should use for your project is Single dozer, and
2) haul distance is greater than 100, and
3) haul distance is less than or equal to 300, and
4) condition of the ground is not true,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE030
=======
If 1) the type and model of construction equipment that you should use for your project is Single dozer, and
2) haul distance is greater than 300, and
3) condition of the ground,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE031
=======
If 1) the type and model of construction equipment that you should use for your project is Single dozer, and
2) haul distance is greater than 300, and
3) condition of the ground is not true,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE032
=======
If 1) the type and model of construction equipment that you should use for your project is Side by side dozers, and
2) condition of the ground,

Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE033
=======
If 1) the type and model of construction equipment that you should use for your project is Side by side dozers, and
2) condition of the ground is not true,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE034
=======
If 1) the type and model of construction equipment that you should use for your project is Shovel, and
2) type of material being excavated is HARD,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE035
=======
If 1) the type and model of construction equipment that you should use for your project is Shovel, and
2) type of material being excavated is MEDIUM,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE036
=======
If 1) the type and model of construction equipment that you should use for your project is Shovel, and
2) type of material being excavated is SOFT,
Then retrieve data base values for several parameters.

ANTECEDENT :: YES

RULE037
=======
If 1) the type and model of construction equipment that you should use for your project is Backhoe, and
2) condition of the ground, and
3) type of earthmoving project is BASEMENT,

Then 1) retrieve data base values for several parameters, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.

ANTECEDENT :: YES

RULE038
=======
If 1) the type and model of construction equipment that you should use for your project is Backhoe, and
2) condition of the ground is not true, and
3) type of earthmoving project is BASEMENT,
Then 1) retrieve data base values for several parameters, and
2) it is definite (100%) that any other required support equipment is SUFFICIENT TRUCKS TO REMOVE EXCAVATION AS REQUIRED. TRUCKS SHOULD HAVE A CAPACITY OF AT LEAST 4 BUCKET LOADS AND THE CAPACITY SHOULD BE A MULTIPLE OF THE BUCKET SIZE FOR MAXIMUM EFFICIENCY.

ANTECEDENT :: YES

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